RESEARCH DEPARTMENT

Compatible single-sideband modulation:

comparisons with double-sideband modulation over high-frequency circuits

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THE BRITISH BROADCASTING CORPORATION
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COMPATIBLE SINGLE-SIDEBAND MODULATION: COMPARISONS WITH DOUBLE-SIDEBAND MODULATION OVER HIGH-FREQUENCY CIRCUITS

Research Report No. E-116

(1965/48)

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Section	Title	Page
	SUMMARY	1
1.	INTRODUCTION	1
2.	THE C.S.S.B. TRANSMISSIONS	2
	2.1. General Considerations	2
	2.2. The Drive and Monitoring Equipment	3
	2.3. Operational Experience	5
3.	TEST TRANSMISSIONS	7
	3.1. Transmissions over the Rampisham/Singapore Circuit	7
	3.1.1. First Series of Tests	7
	3.1.2. Second Series of Tests	8
	3.1.3. Third Series of Tests	8
	3.2. Transmissions over the Rampisham/Ghana Circuit	8
4.	CONCLUSIONS	9
5.	ACKNOWLEDGEMENTS	9
6.	REFERENCES	10

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SUMMARY

Field tests are described which investigate the transmission of compatible-single-sideband signals from a typical high-power transmitter for high-frequency broadcasting and which compare reception of double-sideband and compatible single-sideband signals over circuits of some 3,000 and 7,000 miles (5,000 and 11,000 km).

The tests show that, given suitable monitoring equipment at the transmitter, such modulation can be quite easily achieved and maintained but that, under present conditions, the quality of reception shows no significant improvement over the normal double-sideband signals.

1. INTRODUCTION

Double-sideband (d.s.b.) amplitude modulation has remained in widespread use since the early days of broadcasting, despite the fact that it occupies a channel bandwidth which is twice the base-bandwidth, because it enables receivers to be used which are simple to tune and relatively cheap to make. Development of broadcasting has led to considerable overcrowding in the broadcast bands; a modulation system that provides a signal which occupies a channel bandwidth equal to the base-bandwidth, but yet which can be received equally well on a simple receiver, would appear to have great advantage.

Such a modulation system has recently been proposed[1,2,3,4]; the transmitted signal has (substantially) the bandwidth of a single-sideband signal but the envelope of a double-sideband signal. In principle, such a signal (known as compatible single-sideband (c.s.s.b.)) can be received without distortion on amplitude-modulation receivers employing the usual form of envelope detector. Furthermore, a small improvement in signal-to-noise ratio for the same audio frequency response would be expected if domestic receivers were designed to have narrower radio-frequency bandwidths; they would also then either obtain greater immunity from adjacent-channel interference from the present number of transmitters or, alternatively, the present degree of adjacent-channel interference from an increased number of transmitters. It has also been claimed that c.s.s.b. gives improved reception under conditions of selective fading[2] because of the narrower bandwidth that it occupies.

Whilst the above may be true for perfect receivers, some limitations must be expected of those used for domestic reception. Laboratory tests carried out to study this aspect are described elsewhere[5] and, briefly, they show that, except for some cases of adjacent-channel interference, c.s.s.b. modulation offers little or no improvement over d.s.b. when used with existing types of receiver.

Another aspect is the feasibility of providing c.s.s.b. modulated signals from typical high-power transmitters, from the point of view both of original installation and of day-to-day operation. This report describes the results of tests which were conducted primarily with that aspect in mind, but which were also arranged to give a useful field comparison with the results of the laboratory tests, particularly with regard to reception of c.s.s.b. under conditions of selective fading.

2. THE C.S.S.B. TRANSMISSIONS

2.1. General Considerations

One method of generating a c.s.s.b. signal is to phase-modulate the drive to the transmitter such that when this amplified drive is subsequently amplitude-modulated in the usual way, spectral components exist on only one side of the carrier. Clearly, a particular form of phase modulation is required but practical circuits have, so far, given only an approximation to this ideal. One approach was first described by Kahn[1], who later gave an improved version[2]. An alternative method for providing the phase modulation has been described by Van Kessel[3,4]; the c.s.s.b. modulator used in the present series of tests was of the latter type. In the modulator unit employed, both a c.w. input (in the medium-frequency band) and the a.f. signal are applied; the modulator gives two low-power outputs, a phase-modulated drive and an a.f. output, both of which are applied to the transmitter at the appropriate inputs.

Under these circumstances, the transmitter drive contains significant spectral components on both sides of the carrier frequency extending over a total bandwidth of four times the maximum a.f. Provided the r.f. bandwidth of the transmitter is sufficiently large (and this is usually the case), the transmitter needs no modification because it is required to amplify and to amplitude-modulate this phase-modulated drive in the same way that it amplifies and amplitude-modulates the normal c.w. drive. The ratings throughout the transmitter (and, in particular, the rating of the modulator valves and modulator transformer) are unaffected. It is essential, of course, that the phase modulation should be in step with the amplitude modulation at the modulator stage. Amplitude and phase controls provided on the c.s.s.b. modulator were sufficient to allow for the amplitude and phase characteristics of the particular transmitter used; it is believed that the same would be true for all present-day transmitters. From the point of view of day-to-day operation, the stability of the characteristics of both the c.s.s.b. modulator and the transmitter must also be considered. Medium- and low-frequency transmitters have a high order of stability, but high-frequency (h.f.) transmitters, because of their broadcasting schedules, are re-tuned to different frequencies at frequent intervals throughout each day and night. It was therefore decided to test c.s.s.b. modulation over a h.f. circuit because it represented the worst day-to-day stability problem. In addition, h.f. circuits are likely to provide the most stringent test conditions with regard to noise, selective fading, and co-channel and adjacent-channel interference.

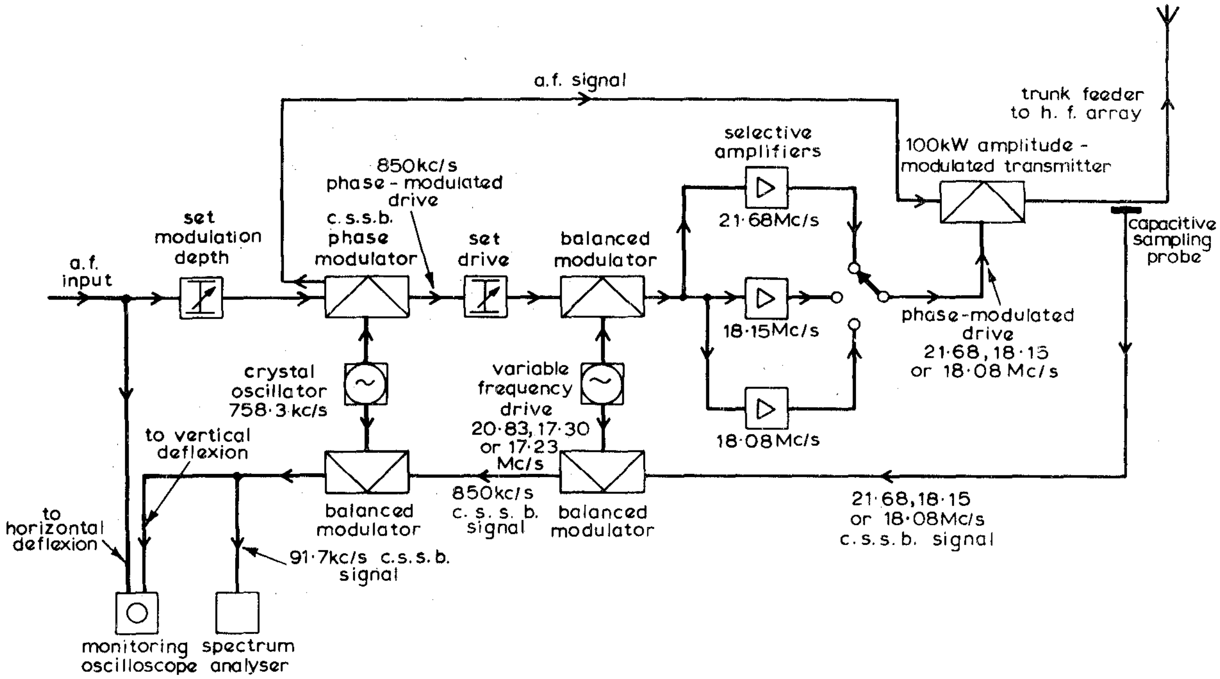
a.f. signal
trunk feeder to h. f. array
selective amplifiers
100kW amplitude - modulated transmitter
850kc/s phase - modulated drive
c. s.s.b. phase modulator
set modulation depth
set drive
balanced modulator
21·68Mc/s
capacitive sampling probe
a.f. input
18·15Mc/s
phase-modulated drive 21·68, 18·15 or 18·08 Mc/s
crystal oscillator 758·3 kc/s
variable frequency drive 20·83, 17·30 or 17·23 Mc/s
to vertical deflexion
18·08Mc/s
850kc/s c. s. s. b. signal
balanced modulator
balanced modulator
21·68, 18·15 or 18·08Mc/s c. s. s. b. signal
to horizontal deflexion
91·7kc/s c.s.s.b. signal
monitoring oscilloscope
spectrum analyser

Fig. 1 - C.s.s.b. drive and monitoring equipment

2.2. The Drive and Monitoring Equipment

Sender 35, at Rampisham, was chosen for the tests because its design is typical of current h.f. transmitters. It is a 100 kW, high-level anode-modulated transmitter with overall negative feedback, having pre-set motorized tuning controls. The c.s.s.b. modulator provided a basic phase-modulated signal at 91•7 kc/s; facilities were provided within the modulator unit whereby this could be heterodyned by an external oscillator to any frequency in the medium-frequency band. Additional equipment was constructed in Research Department which would heterodyne this drive to the chosen high frequencies and also, for convenience, would monitor the spectrum and the envelope of the radiated signal. This additional equipment is shown block-schematically in Fig. 1. The a.f. signal was fed both to the c.s.s.b. modulator and to the X plates of a monitoring oscilloscope. A local oscillator at 758•3 kc/s provided the c.w. drive for the modulator unit and resulted in a phase-modulated output signal at 758•3 + 91•7 = 850 kc/s. This, after mixing with the output of a variable h.f. drive, provided the phase-modulated h.f. transmitter drive. Three selective amplifiers were provided, each tuned to one of the three carrier frequencies to be used for the tests; the output of the appropriate amplifier was fed to the transmitter.

Balanced capacitive sampling probes were attached to the trunk feeder outgoing from the transmitter; the frequency of the signal from these was reduced to 91•7 kc/s as shown in Fig. 1, using the same heterodyning oscillators as used to provide the drive. In this way a c.s.s.b. signal was obtained for monitoring purposes having a frequency stability equal to that of the crystal source within the c.s.s.b.

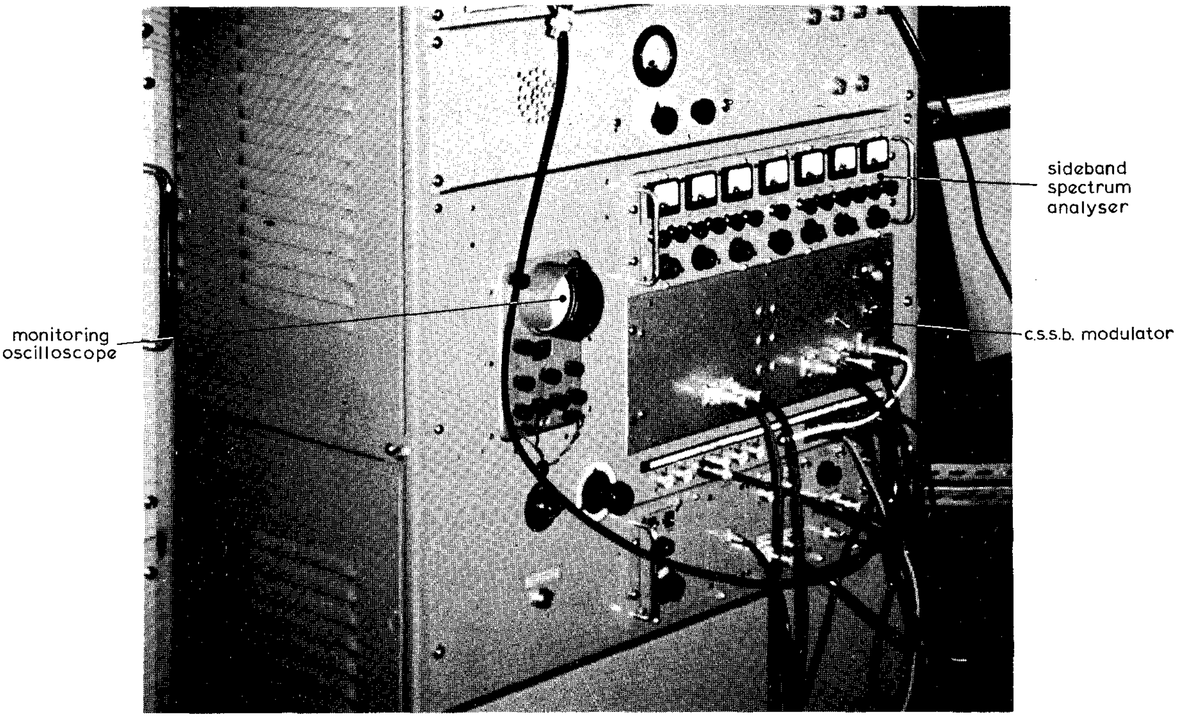

Fig. 2 - The c.s.s.b. drive and monitoring equipment

modulator. This 91·7 kc/s signal was fed to both a spectrum analyser and the Y plates of the monitoring oscilloscope. Except for the drive oscillator, the drive and monitoring equipment was mounted on a single panel measuring 21 in. × 32 in. (535 mm × 814 mm), shown in Fig. 2; the transmitter was not modified in any way. The c.s.s.b. modulator and transmitter was set up initially, and checked before and after each transmission, using 900 c/s and 7 kc/s tones. The trapezium display on the oscilloscope gave a good indication of the modulation depth and linearity but the actual percentage distortion and the modulation depth was measured using the station equipment in the normal way.

The sidebands of a c.s.s.b. signal comprise components differing in frequency from the carrier by the modulation frequency and its harmonics. Where more than one modulation frequency is present there will also be combination terms. The harmonic and combination terms are at a fairly low level but, even for perfect equipment, they are necessary (in the upper sideband only) in order to provide a distortionless envelope[3,4]. The c.s.s.b. modulator and the transmitter provided an envelope which was substantially distortionless but, because the phase modulation was not perfect, harmonic and combination terms occurred at low level in both the upper and lower sidebands. As part of the setting-up procedure, the controls on the c.s.s.b. modulator were adjusted with single-tone modulation so as to achieve optimum suppression of all components in the lower sideband. Using modulation frequencies of 900 c/s and 7 kc/s at 40% modulation depth, all components of the lower sideband could be suppressed by at least 30 dB relative to the carrier. These adjustments were made daily by the station staff before each test transmission; the resulting levels were recorded before and after each test transmission.

To facilitate these adjustments and measurements, the spectrum analyser already mentioned was built specifically for the tests and was designed to display simultaneously on seven meters the relative levels of the carrier, and the first-, second- and third-harmonic terms in the spectrum of the upper and lower sidebands, using either 900 c/s or 7 kc/s tone modulation, over the range of levels +6 dB to -40 dB relative to that of the carrier.

The analyser is shown block-schematically in Fig. 3.* The input (at 91·7 kc/s, see Fig. 1) was applied to a distribution amplifier which fed seven similar chains. In each chain, a local oscillator produced a signal in the frequency range 30 c/s to 100 c/s by beating with a particular spectral component of the incoming signal. This beat-frequency signal was selected by a low-pass filter, amplified, detected and displayed on the appropriate meter. The chain associated with the carrier component incorporated an amplifier of fixed gain; a 'set-level' control at the input (which was adjusted to produce a reference carrier-level indication in the absence of modulation) set the overall gain of the analyser and enabled the amplitudes of all the components to be read off the meter, in decibels, relative to that reference level. The six sideband chains included an additional amplifier with gain that could be set to 0 dB, 10 dB, 20 dB, or 30 dB depending upon the level of the appropriate spectral component. The local oscillators could be switched to pre-set frequencies corresponding to modulation frequencies of either 900 c/s or 7 kc/s; each oscillator included a trimmer to allow for long-term drift up to ± 150 c/s. The whole was transistorized and mounted in a framework 19 in. × 5¼ in. × 8½ in. deep (482 mm × 133 mm × 216 mm). This small overall size was due particularly to the use of active low-pass filters in each chain rather than the conventional L-C type. These filters were based on the shunt-feedback amplifiers described in Reference 6.

2.3. Operational Experience

It was found that the controls on the c.s.s.b. modulator could be readily adjusted (using tone modulation, see Section 2.2) for optimum suppression of all the components of the lower sideband. With 40% modulation depth, a suppression of about 30 dB relative to the carrier was achieved. This degree of suppression was well maintained without further adjustment throughout the three-hour period of the transmissions; only small further adjustments were required from day to day.

The percentage distortion of the radiated envelope (measured daily using the normal station equipment) was typically 1% to 2% for both d.s.b. and c.s.s.b. when modulating to 80% depth at 400 c/s.

The possibility of radiating only the lower sideband (instead of only the upper sideband) was investigated because it may be convenient to make this change, for point-to-point working, whenever the receiving station suffers adjacent-channel interference on one side only. It was found that, because of the design of the c.s.s.b. modulator, and the frequency response of the selective amplifiers, this change could not readily be made but, if this facility were required, the design of the modulator and of the amplifiers could be altered to provide it.

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* The circuit design of the analyser was largely the work of Dr. J.B. Izatt.

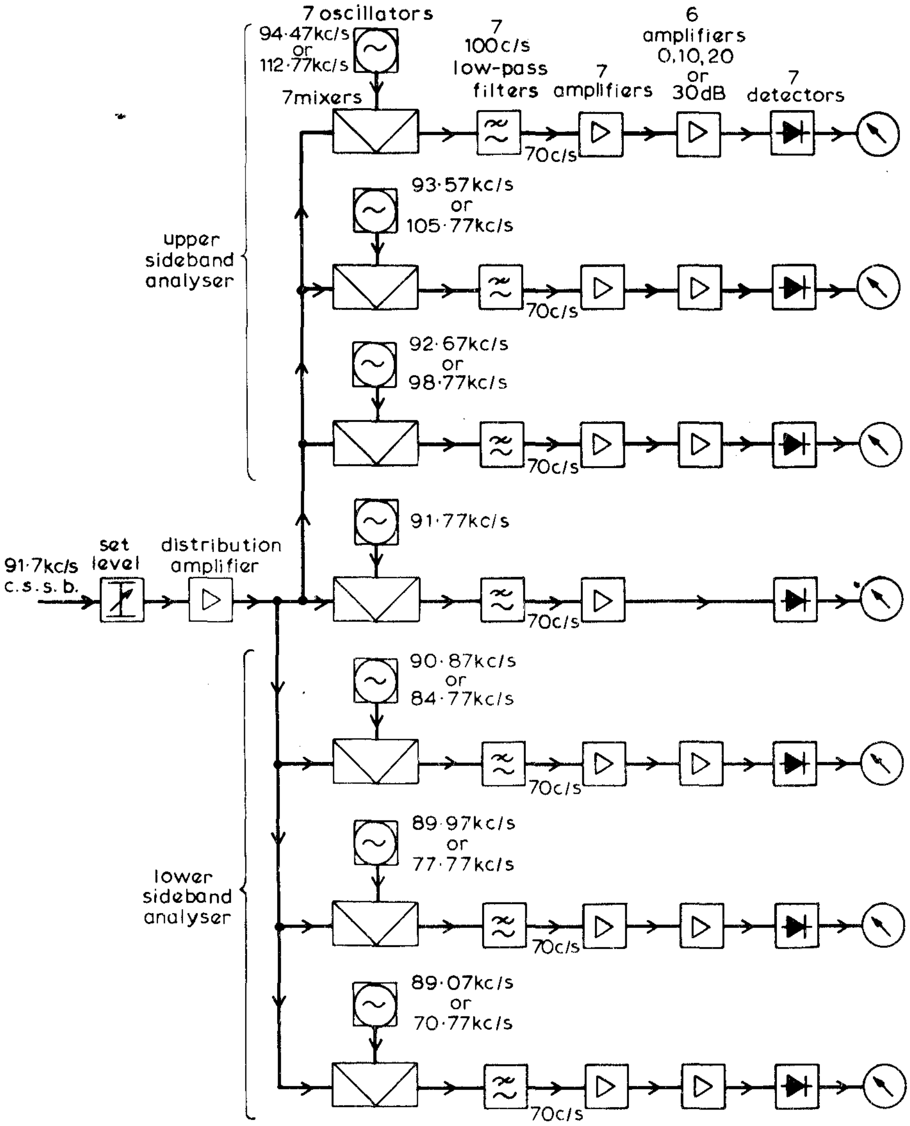

Fig. 3 - Block schematic diagram of spectrum analyser

3. TEST TRANSMISSIONS

3.1. Transmissions over the Rampisham/Singapore Circuit

This circuit is a 3- or 4-hop path of about 6,700 miles (10,800 km) which, over the period of the transmissions (0930 to 1300 hrs GMT), was about 90% daylight. It is used for the BBC General Overseas and Eastern Services, for direct domestic reception in the Far East and also for h.f. re-broadcast. Using 18·15 Mc/s and 21·68 Mc/s, the circuit normally gives favourable reception; those frequencies were also used for the c.s.s.b. test transmissions, described in the next sections. The test signals were received at the BBC (Woodleigh) receiving station, using a rhombic aerial and an AR88 (double-sideband) receiver with ± 5 kc/s i.f. bandwidth, as for the normal d.s.b. transmissions. The median field strength at the receiving site was about 300 μV/m.

The staff at Singapore were asked to tune the receiver for optimum reception, and were not told whether c.s.s.b. or d.s.b. modulation was being used. They were asked to report the quality of reception at hourly intervals according to the SINPO code* and, where possible, to make tape recordings of the received signals.**

3.1.1. First Series of Tests

The first series of tests, from 23rd March to 25th April and from 10th May to 23rd May 1964 inclusive, used the regular BBC programme for the modulation. This programme was radiated simultaneously on 18·15 Mc/s and 21·68 Mc/s from 1000 hrs to 1300 hrs GMT daily. C.S.S.B. modulation was used on one frequency, d.s.b. modulation on the other, the two being interchanged on alternate days.

The staff at Singapore reported no distinct advantage using either type of modulation. The nature of the reproduction was slightly different for c.s.s.b. and for d.s.b.; for example, the staff were of the opinion that c.s.s.b. modulation gave speech a certain 'hardness' which, if anything, slightly improved its intelligibility but no strong preference was expressed. Neither type of modulation showed a clear advantage with regard either to selective fading or interference.

These opinions were confirmed by several experienced*** listeners when listening to the tape recordings, but it became apparent that, since the programme material consisted almost entirely of foreign-language speech, no critical comparison could be made. Furthermore, the difference between the propagation conditions at the two frequencies from day to day was so much greater than any difference that may have existed between the two types of modulation that very prolonged tests would have been required if a reliable conclusion were to be drawn.

The test conditions were therefore changed, and two further series begun.

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* This is a code widely adopted when reporting h.f. reception conditions. It covers Signal strength, Interference, Noise, Propagation disturbance, frequency of fading, modulation quality, modulation depth, and Overall merit. Each is reported on a scale from 1 to 5, the larger figures corresponding to better reception in each case.

** A few tape recordings of the same signals were also made at the All India Radio station at Jaipur, near Delhi, but careful listening tests showed them to be very similar to those made at Singapore and they will not be dealt with further here.

*** i.e. listeners experienced in the problems and requirements of h.f. reception.

3.1.2. Second Series of Tests

For this series, conducted from 24th May to 12th July 1964 inclusive, one of the two daily transmissions (from 1000 hrs to 1300 hrs GMT) used d.s.b. modulation throughout (as for Section 3.1.1) whilst the other used c.s.s.b. modulation from 1000 hrs to 1100 hrs and from 1200 hrs to 1300 hrs, interleaved with d.s.b. modulation from 1100 hrs to 1200 hrs. This modulation schedule was interchanged between the two carrier frequencies (18·15 Mc/s and 21·68 Mc/s) on alternate days, using the regular BBC programme for modulation as for the first series of tests. Interleaving the c.s.s.b. and d.s.b. transmissions at hourly intervals in that way enabled comparisons to be made under near-constant propagation conditions.

As for the previous series of tests, the staff at Singapore reported slight differences between the two types of modulation but neither showed a distinct overall improvement. Again, this was confirmed after extensive and critical comparison of the tape recordings.

3.1.3. Third Series of Tests

This series was conducted concurrently with the second series, using programme material which was specifically chosen to facilitate a critical comparison between the two types of modulation.* This material was radiated as a special test programme from 0930 hrs to 0950 hrs, first using d.s.b. modulation and repeated immediately using c.s.s.b. modulation, on 7th and 14th June (using 21·68 Mc/s), and on 8th and 15th June 1964 (using 18·15 Mc/s). Tape recordings of the signals received at Singapore were edited and re-arranged so that critical direct comparisons could be made between the original programme and the signals received using the two types of modulation.

The recordings were played to several panels of experienced listeners. The distortion due to fading appeared slightly different in character for the two systems, and a small difference in the subjective annoyance of the distortion was sometimes noted, in which case the preferred system depended on the nature of the programme material. In the case of male speech c.s.s.b. was marginally better while for some types of music d.s.b. was marginally better. These assessments included the effects of slight interference and noise, but distortion was the most important degradation.

3.2. Transmissions over the Rampisham/Ghana Circuit

The Rampisham/Singapore circuit normally gives favourable reception (e.g. for 'Overall merit' it is typically rated 'fair' to 'good') and, in the light of the above results, it was suggested that c.s.s.b. modulation may be found preferable to d.s.b. modulation over other, less favourable, circuits. Accordingly, the special test programme was radiated on 18·08 Mc/s from Rampisham to Ghana from 1835 hrs to 1855 hrs GMT. This circuit is a 2- or 3-hop path of about 3,200 miles (5,100 km) which, over the period of the transmissions, was about 100% twilight and subject to severe fading. The programme was radiated, first using d.s.b. modulation and repeated immediately using c.s.s.b. modulation, on 24th, 25th and 26th August 1964 and 17th, 18th and 19th September 1964; the transmissions were received on a rhombic aerial at the Ghana Broadcasting and Television Service receiving station near Accra.

* This programme material, selected by Audio Frequency Section of Research Department, included piccolo, glockenspiel, piano, dance music, male speech and female speech.

The three transmissions in August were invalidated because a single-sideband receiver was used at Accra. The three transmissions in September were received on a Racal double-sideband receiver with ± 1·75 kc/s i.f. bandwidth; tape recordings were made of the receiver output.

Due to severe local interference, no conclusions could be drawn from the tests of 17th and 18th September. The severe bandwidth restriction of the receiver made it difficult to compare the c.s.s.b. and d.s.b. reception on 19th September but, under the conditions imposed, neither system of modulation showed any distinct advantage. It was considered unlikely that an advantage would have been observed had a greater bandwidth been used, but time was not available to confirm that view.

4. CONCLUSIONS

This report shows that, with the monitoring facilities provided, c.s.s.b. modulation was readily achieved and maintained from day to day on a high-power h.f. transmitter of typical present-day design. It is considered that the same would be true for other modern h.f. transmitters, and for medium-frequency transmitters; similar monitoring facilities would be necessary but, depending upon the broadcast schedules, one set could probably be common to several transmitters. Unwanted-sideband suppression of about 30 dB was readily maintained; the distortion (typically 1% to 2%) was similar to that of d.s.b. modulation.

Whilst the use of either d.s.b. or c.s.s.b. modulation affected the 'character' of the received signals, neither type of modulation was distinctly superior over the two h.f. circuits used for the tests. Both types of modulation appeared to be equally affected by selective fading and by adjacent-channel interference. The types of distortion were different for the two systems of modulation; on music they were equally disturbing or slightly more disturbing on c.s.s.b., while on male speech the c.s.s.b. signals appeared, if anything, to possess a 'hardness' which gave slightly better intelligibility.

In summary, therefore, the tests have shown that c.s.s.b. modulation requires a little more complexity at the transmitter and that, over typical h.f. circuits, it makes no significant improvement or degradation. Separate laboratory investigations[5] show that c.s.s.b. might cause more or less interference to other services depending on the sideband positioning. These various factors would require to be carefully weighed in any attempt to evolve an improved 'plan' based on c.s.s.b.

5. ACKNOWLEDGEMENTS

The work described in this report resulted from close co-operation between departments within the BBC and between the BBC and other authorities. Thanks are due to Messrs. Philips (Eindhoven) Ltd. who loaned the modulator unit and to Dr. Stumpers and Mr. van Kessel, of that organization, for their helpful discussions during the tests; to All India Radio and the Ghana Broadcasting and Television Service who made tape recordings of the received signals; to the Engineer-in-Charge and staff at the BBC receiving station at Woodleigh (Singapore) who made both tape recordings and subjective reports of the received signals; to the Engineer-in-Charge and staff at Rampisham who co-operated fully in radiating the test transmissions, and to C.E.X.B.'s Department of the BBC for arranging the test transmissions and co-ordinating with the receiving authorities.

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